Synopsis for Registration as Research Student
For

Doctoral Degree
On

Sediment Classification of Tropical Littoral Water Using SONAR System

By

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Abstract:

Tropical regions like India witness concentration of monsoons within three months of the year resulting in high rate of flow during the period. The high rate of flow manifests as high siltation in the reservoirs created for storing water for the long dry spell post monsoon. The incessant siltation during the monsoon period over the years depletes the storage capacity of the reservoirs created at very high cost. The present situation in India is really critical and urgent measures for de-siltation is called for to ensure reasonable availability of water resources for varied applications. De-siltation efforts require precise sediment classification for effective water resource management. The satellite remote sensing followed by image analysis has been the most popular method to undertake such sediment analysis for reservoirs due to convenience. However, such methods have significant limitations in terms of inaccuracies of measurement and analysis of sediments. Acoustic methods can substantially enhance the measurement and analysis accuracies.

Analysis of the details and structure from the sonar backscatter signal provides the means to classify sediments to determine the composition (sand, rock, mud etc.), the vegetation cover and to extract other information including geotechnical properties. Acoustic techniques suffer from being sensitive to the medium fluctuations so analysis becomes site specific. The major factors that affect backscatter signal quality are sound speed, bottom type and settings of Echo-Sounder such as angle of incidence, beam width, frequency of operation etc. So features extracted from backscatter signal/image must be scale and rotation invariant. This work focuses on improvement in sediment classification performance using scale and rotation invariant feature extraction techniques.

This work aims at study and modeling of tropical littoral fresh water environment, simulation and analysis of tropical littoral fresh water channel impulse response. Effect of physical parameters of underwater channel on quality of SONAR backscatter signal will also be discussed in this research work. Tropical littoral fresh water environment of Khadakwasala Lake situated in Pune will be taken under consideration for this research.

1. Introduction :

Water reservoir capacities have been created at huge cost, infrastructure investment and the government continues to spend huge sums each year for creating additional storage capacities. Most of the developed projects have not been yielding expected output, primarily due to underestimation of sedimentation problems [1].

History reveals that great amount of sediment is carried out by Indian rivers down to reservoirs, lakes, estuaries, bays at a rate of 2000-3000 tonnes/km^2/year in north east to 500-1000 tonnes/km^2/year in central and southern regions, out of which 29% is transported to sea and 10% deposited in reservoirs [2][3]. Such deposition causes loss of storage capacity and could adversely affect planning for long term utilization of reservoir storage capacity for irrigation, power generation, industry, urban power supply and flood moderation [4].

The satellite remote sensing is very useful, economical and reliable tool for conducting monitoring sedimentation in lakes or reservoirs [5]. However, this method is inaccurate and does not incorporate the precise sediment type such as sand, mud, rock etc.

Use of acoustic signals obtained from **Active Sound Navigation And Ranging (SONAR)** system, combines the bottom mapping capability with the identification of the type of bottom material based on the features of echo signal received. Therefore, significant research effort has been dedicated to methods allowing for classification of the sea/river sediments using acoustic techniques [6].

Sea and river sediment classification can be divided in two categories: model based method and empirical method [7]. In model based method, theoretical models are used to predict the characteristics of sediments for a given environmental condition. The application of model based studies using echo sounding backscatter data requires close grid sediment ground truth information. This method needs frequent and time consuming sediment sampling for determination of ground truth data.

Empirical method relies on the studies of echo signal features that are correlated with sediment properties. In active SONARS, transmitter sends sound pulse of frequencies typically 33 KHz, 210 KHz of short duration which will get hit with the riverbed, part of the signal energy will be reflected in coherent direction and some of the energy will be scattered in random direction. The part of energy that gets reflected back to the source is called as “Backscattered” energy. Features of backscatter signal are used for sediment classification [8].

A large part of the research on use of acoustic technique for sediment classification has focused on active SONAR systems. Now days there are widely available acoustic systems such as Single-Beam Echo-Sounders (SBESs), Multi-Beam Echo-Sounders (MBESs) and Side Scan SONAR (SSS) [7]. Single-Beam and Multi-Beam Echo-Sounder provides one dimensional signal while **Side Scan SONAR translates echo signals into pixel values which are presented as dark and light gray shades that leads to formation of acoustic images.**

Sound is the only signal that propagates underwater. The underwater medium from acoustic perspective is typically defined based on sound speed profile. **Speed of sound** is highly dependent on underwater medium properties such as **Temperature, Pressure and Salinity so characterization of underwater channel becomes more challenging [9]. The tropical Indian** waters further add to the challenges due to random fluctuations of the medium characteristics based on diurnal and seasonal variation in temperature. **The major factors that affect backscatter signal quality are, sound speed, bottom type and settings of Echo-Sounder such as angle of incidence, beam width, frequency of operation etc.**

2. Literature Review:

Steven Tyner et.al. (2014) presented classification of seabed from underwater video. Five different seabed types are taken under consideration. Features such as number of edges, mean color, energy of symmetric bi-orthogonal wavelet coefficients, correlation coefficient of Gray Level Co-occurrence Matrix (GLCM) with horizontal and vertical orientation and six displacement values of 1, 2, 3, 8, 16, 32 pixels are used. Author presents use of K-NN, Polynomial and Radial Basis Function (RBF) kernels of the Support Vector Machine (SVM) techniques for classification. SVM classification results are presented by considering three kernel functions namely Linear, Radial Basis and Third order Polynomial. Optimal value of sigma parameter selected for Radial Basis Function selected is 1 which results in average cross validation error of 8.4% compared to 13.2% in case of Linear kernel. Database consists of total 111 images. Multiclass SVM and Neural Network classifier could be explored [10].

Parastoo Qarabaqi et.al. (2013) presented characteristics of underwater channel. Multipath underwater channel propagation. Each propagation path is modeled as large-scale gain and micro multipath components that cumulatively result in a complex Gaussian distortion. Statistics of

path gains estimated using data collected from Kauai Island, Hi, and USA in year 2011. Transfer function of each path is presented by using Bellhop ray tracing model. Comparative analysis of Rice and Rayleigh fits for direct path, bottom reflected and surface reflected paths are discussed in this paper. Author suggest use of hypothesis testing for characterization of surface and bottom reflected path impulse response [11].

Milica Stojanovic et.al. (2013) presented multipath intensity profile of underwater channel. Probability density function of impulse response from surface reflected, bottom reflected path is analyzed for Rice and Rayleigh distributions. Relation between absorption coefficient and frequency of SONAR operation is presented in this paper. The results showed that for higher frequency signal absorption will be more which makes higher frequencies suitable to shallow water only. A distinguishing property of acoustic channels that the path loss depends on the signal frequency is presented in this paper. Use of chi-square test, KS test could be explored [12].

Huu-Giao Nguyen et.al. (2012) describes seabed characterization and recognition of sonar images using key point based approaches to address the invariance to contrast change and geometric distortions. For detecting points of interest, detectors such as Difference of Gaussian (DoG), Fast Hessian Detector (FH) and Harris Detector are used. To match the points across different images of same texture descriptors like Scale Invariant Feature Transform (SIFT) and Speeded up Robust Feature (SURF) are implemented. Characterization of detected keypoints is carried out based on spatial statistics which uses spatial keypoint statistics and Log Gaussian Cox model. Combination of detectors and descriptors are applied to K-NN, SVM and Random Forest (RF) classifiers. Greater accuracy of classification of seabed is obtained using SVM and RF classifiers. Six different classes are taken under consideration. Use of Log Gaussian Cox model shows accuracy of 93.14%, 92.15%, 93.65%, 87.35%, 90.5%, and 91.34% for Mud, Sandy Mud, Gravey Sand, Clearly Sand, Rock and Mixed Sediment respectively. This work suggests that statistical model such as Neyman Scott, Shot noise Cox or Gibb's Process can be investigated. Comparison of Log Gaussian Cox model with powerful statistical tools, including goodness-of-fit or hypothesis test can be explored [13].

Mirjam Snellen et.al. (2013) presented sediment classification methods based on multi-beam echo-sounder backscatter. Backscatter data collected collected from Dordtse Kil river Netherlands. Authors proposed two methods, first is Bayesian estimation method that uses average backscatter data per beam for classification and second method uses a model based technique based on Kirchoff and Composite roughness model. Use of average backscatter data per beam makes the classification independent of quality of the MBES calibration. The Applied Physics Laboratory, University of Washington (APL UW Model) is used for calculation of backscatter strength. Comparative analysis of measured backscatter signal and calculated backscatter signal is presented in this paper. For every grazing angle backscatter strength data is fitted into normal distribution. Bayesian method is used for the backscatter values per angle, for sediment classification [14].

Ahmed Nait-Chabane et.al. (2013) uses combination of features extracted from GLCM and directional filter bank (DFB). The approach uses a decomposition of the Fourier spectrum into three spectral bands low, medium and high frequencies. Comparative analysis of Haralik features, Spectral features and the combination of both features (including effect of grazing angle) shows accuracy of 76.06%, 78.18%, and 82.13% respectively by using Native Bays Classifier and use of Multilayer Perceptron shows accuracy of 95.43%, 93.18%, and 99.05% respectively. Unsupervised algorithm K-means clustering and SOFM does not show promising results. Four classes of sediments are analyzed: sand, rock, ripple, posidonia. The misclassification is higher for ripples and posidonia [15].

Dimitrios Eleftherakis et.al. (2012) discussed riverbed classification using MBES. The Kongsberg EM3002 SONARs with single-head multi-beam echo-sounder were used in the survey. This sonar is well suited for shallow water depths as its high frequency ensures narrow beams with small physical dimensions.The operational frequency selected is 300 kHz. Three cases of sediment classification are investigated: classification based on backscatter features, classification based on depth residual feature and hybrid approach using both the features. The method fits a number of Gaussian Probability Density Functions (PDFs) to the histogram of the backscatter data at a given incident angle. The optimum number of PDFs is found by consecutively increasing the number of PDFs until a chi-square distributed test statistic becomes

less than a critical value. For each surface patch of 0.5 m x 0.5m features extracted from backscatter signals are mean, standard deviation, minimum value, maximum value, median and higher order statistical moments (skewness, kurtosis). Determining the optimum set of features is carried out by using Principal Component Analysis. First and second principal components account for 96.4% and 2.4% of the variability of the data, respectively. The first two PCs are fed to the K-means clustering method [4].

Chanchal De et.al. (2009) describes acoustic characterization of seafloor sediment in the western continental shelf of India using the echo features extracted from single-beam Echo-Sounder at normal incidence angle. SONAR is operated at dual frequency of 33 KHz and 210 KHz. Combined two frequency inversion approach have been explored for improved characterization of Sea floor. Temporal backscatter model developed by Sternlicht and de Moustier is employed here for model-based characterization of seafloor sediments. The linear regression analysis (between the estimated mean values of $M\varphi$ and the laboratory-measured values of $M\varphi$) shows that the correlation coefficients are 0.98, 0.96, and 0.97, respectively for 33 kHz, 210 kHz, and 2F inversions. The comparison of the results with ground truth at two operating frequencies revealed that this hybrid method could be efficiently used for sediment classification [16].

Imen Karoui et.al. (2008) describes characterization of seafloor/riverbed using a set of empirical distributions estimated on texture responses to a set of different filters. Similarity measures are twofold: first is, each filter is weighted according to its discrimination power and additional weight is evaluated as an angular distance between the incidence angles of compared texture samples. Second method used is based on similarity between global region texture and predefined prototypes. A Bayesian Framework is used where conditional likelihood is expressed using similarity measure between local pixel statistics and seafloor prototype statistics. The results show that the performance of the Bayesian approach depends on the size of analysis window so selection of window size can be explored [17].

Christian Molder et.al. (2008) provides an overview on two image processing techniques, sediment layer contour extraction and inter-layer texture analysis to characterize the recorded data. From the resulting image, two attributes- shape of sea/river bottom and textural information

under horizon are obtained. Features extracted from GLCM are homogeneity, contrast, entropy, correlation, directivity, uniformity and maximum probability. The co-occurrence matrices are computed for 0, 45, 90 and 135 degrees. Wavelet 2D, Wavelet Packet 2D and the Over-Sampled Wavelet 2D transforms are used for image analysis in spectral domain. Features extracted from approximate wavelet coefficients are energy, entropy and mean. Accuracy of rock and sand is 87%, mud is 76%, Plateau is 66%, and Grit is 50%. Feature selection techniques can be explored for reduction in size of feature vector [18].

3. Motivation:

Water and energy are tightly interlinked and highly interdependent. Freshwater and energy are crucial for human well-being and sustainable socio-economic development. Their essential roles in achieving progress under every category of developmental goal are now widely recognized. Hydropower development is one of the most prominent resources for future economic development of any country [1].

India and many third world countries depend on rainfall for their domestic and other freshwater requirements. The non-monsoon months that constitute around 65 % of the period annually, is supported by the water stored in the reservoirs. However, due to the process of water flow and accumulation, the silt in the water from the rivers settle in the reservoirs referred as siltation. Deposition of sediments in reservoirs increases the magnitude, frequency and severity of flood. So it becomes vital to analyze pre-impoundment and post-impoundment sediment texture and density.

Acoustic methods being employed for other applications and other domains have significant potential in analyzing underwater sediments and finds relevance for enhancing the performance of de-siltation efforts. Acoustic methods can substantially enhance the measurement and analysis accuracies; however these techniques are highly sensitive to the medium properties of the underwater medium [19]. The sound speed underwater is dependent on temperature, pressure and salinity. Variation in sound speed results in variation in backscatter strength. So the analysis becomes **site specific**.

Understanding of the channel properties plays a vital role in classification of sediments.

4. Sediment Classification System Overview:

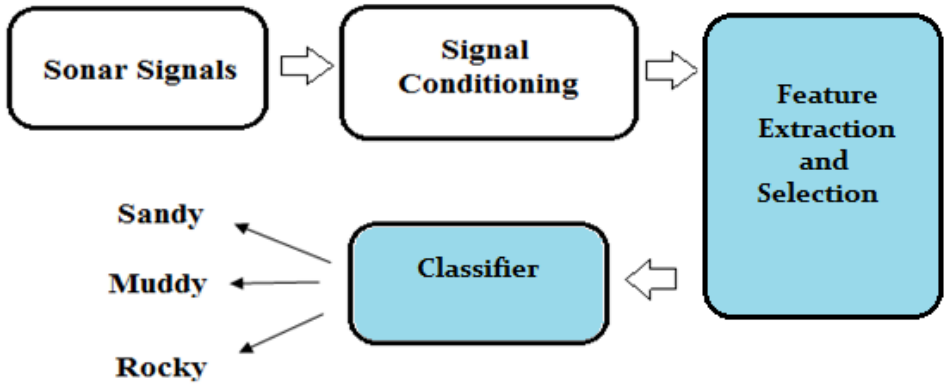

Figure 1. General Flow of Sediment Classification System

Figure 1 shows sediment classification system that includes stages like preprocessing, feature extraction, selection and classification. Since the quality of backscatter signal/image data is highly dependent on physical properties of water channel such as sound speed along the water column as well as settings of Echo-Sounder such as beam width, grazing angle, frequency of operation etc.[20][21], the features used for classification must be **scale and rotation invariant.**

5. Aim and Objectives:

Aim of this research is to classify tropical littoral water sediments by using Active SONAR backscatter signal/image data. This work also aims at improvement in sediment classification accuracy by the use of scale and rotation invariant feature extraction techniques. Analysis of effect of channel characteristics on classification performance will also be evaluated.

Objectives of Proposed Work are as Follows:

1. Study and modeling of tropical littoral fresh water environment like Khadakwasala Lake.
2. Simulation and analysis of underwater channel impulse response and effect of physical parameters of underwater channel on quality of SONAR backscatter signal.
3. Study of existing scale and rotation invariant feature extraction techniques for sediment classification.

4. Development of new feature extraction techniques for sediment classification.
5. Performance evaluation of developed feature extraction techniques.

6. Methodologies and Techniques to be used:

1. Simulation of sound speed equations for tropical fresh water environment using MATLAB.
2. Simulation of channel impulse response using suitable ray tracing underwater channel simulator.
3. Ascertain goodness of fit of different statistical distributions for impulse response of surface and bottom reflected paths using Kolmogorov-Smirnov test and chi square test.
4. Determine effect of sound speed value on sonar signal/image quality using mathematical models.
5. Extraction of relevant features using spatial scale, rotation invariant feature extraction techniques such as Keypoint Analysis and Rotated Complex Wavelet Transform .
6. Ranking of features for selection of dominant features.
7. Evaluation of effectiveness of keypoint detection techniques by using second order spatial statistics such as LOG Gaussian Cox model or Neyman–Scott or Shot-noise Cox or Gibbs processes.
8. Benchmarking of classification accuracy with existing classifier.

Database Description: For this research work available database of EdgeTech DF1000 Side-Scan SONAR image data, project REBENT, IFREMER (Location: France) will be used.

7. Conclusions Expected:

- Increased understanding about tropical littoral water.
- Characterization of impulse response of fresh water reservoir.
- Analysis of SONAR textures using statistical and spectral features.
- Analysis of effect of underwater sound speed on SONAR signal/image quality and its impact on classification accuracy.
- Improvement in accuracy of sediment classification over the existing algorithms by the

use of feature extraction techniques that are scale and rotation invariant.

- Evaluation of performance of the proposed algorithms on available database (EdgeTech DF1000 Side-Scan SONAR image data, a part of project REBENT, IFREMER France).

Equipments Required: Echo-Sounder (Dual frequency 33 KHz and 210 KHz).

Development Tools: MATLAB/SciLab, Ray Tracing Simulator, Bellhop.

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Work Plan:

Sr.	Action	Apr 2016 To Aug 2016	Sep 2016 To Oct 2016	Nov 2016 To Jan 2017	Feb 2017 To Apr 2017	May 2017 To Aug 2017	Sept 2017 To Oct 2017	Nov 2017 To Feb 2018	Mar 2018 To Aug 2018	Sep 2018 To Nov 2018	Dec 2018 To Jul 2019	Aug 2019 To Jan 2020	Feb 2020 To Jun 2020
1	Literature Review												
2	Research problem definition												
3	Study and modeling of sound speed profile at khadakwasala lake												
4	Simulation of underwater channel impulse response using channel simulator and statistical analysis of surface and bottom reflected paths												
5	Preparation of Conference /Journal Paper												
6	Effect of underwater physical parameters on SONAR backscatter signal/image quality												
7	Preparation of journal paper												
6	Planning of the experiment for data collection. Data analysis.												
7	Study of existing scale and rotation invariant feature extraction techniques for sediment classification												

8	Performance evaluation of existing feature extraction techniques on real data												
Sr.	Action	Apr 2016 To Aug 2016	Sep 2016 To Oct 2016	Nov 2016 To Jan 2017	Feb 2017 To Apr 2017	May 2017 To Aug 2017	Sept 2017 To Oct 2017	Nov 2017 To Feb 2018	Mar 2018 To Aug 2018	Sep 2018 To Nov 2018	Dec 2018 To Jul 2019	Aug 2019 To Jan 2020	Feb 2020 To Jun 2020
9	Preparation of Journal paper												
10	Development of new feature extraction techniques for sediment classification												
11	Performance evaluation of developed algorithms												
12	Interpretation of results. and report												